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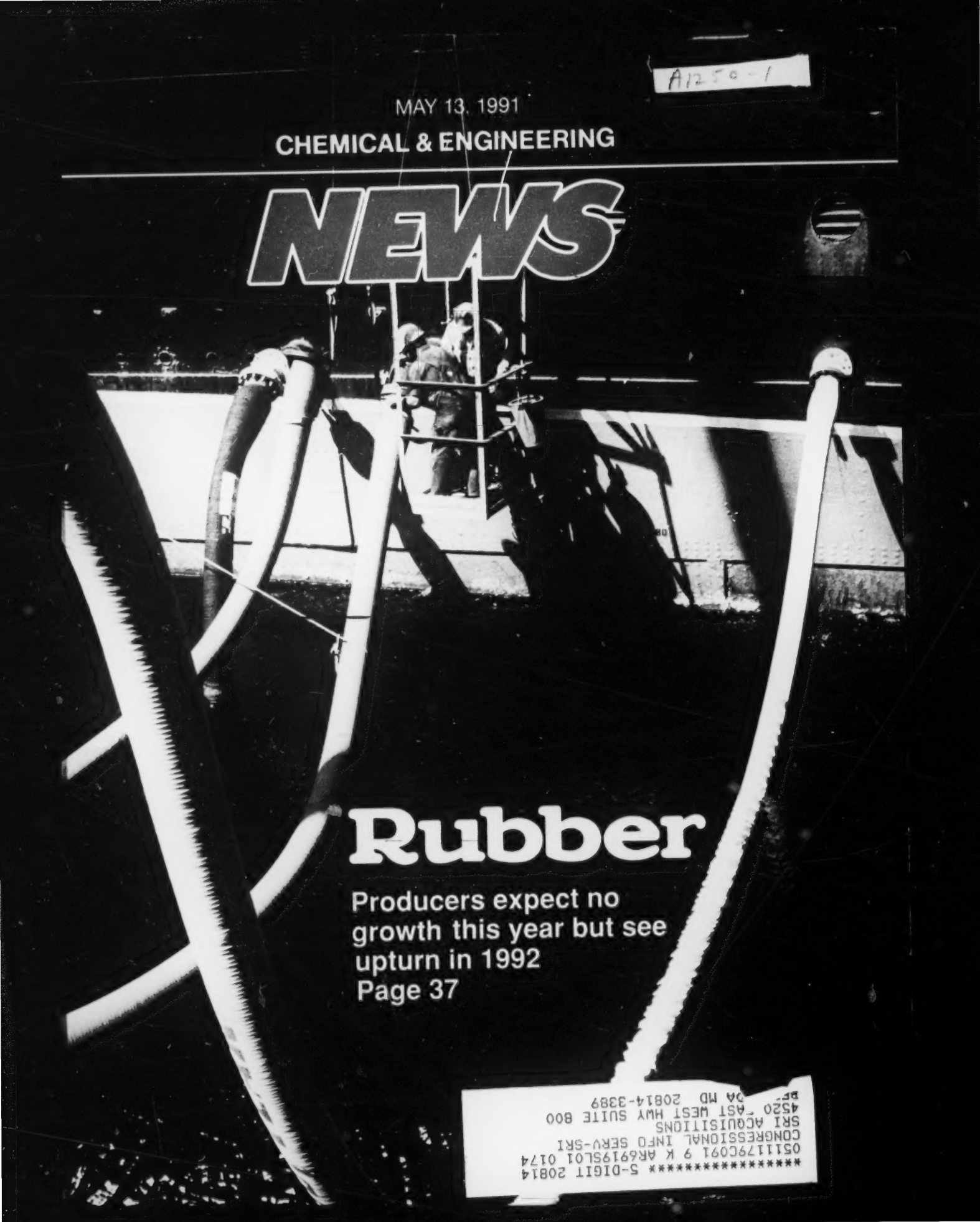
MAY 13, 1991

CHEMICAL & ENGINEERING

NEWS



Rubber

Producers expect no growth this year but see upturn in 1992

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MAY 13, 1991

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News of the Week

■ **Explosion and fire at Louisiana nitroparaffin unit leave eight dead, 120 injured, and destroy Angus Chemical's plant.** **Page 6**

■ **David Baltimore abandons defense of former collaborator and paper they coauthored; but his apology is rejected by researcher who challenged paper's validity.** **Page 7**

■ **Office of Technology Assessment finds bovine growth hormone safe for cows and safe in meat and dairy products for humans.** **Page 7**

■ **Possibility of contaminated virus cultures brings new twist to protracted U.S.-French dispute over discovery of HIV virus.** **Page 8**

Cover: Photo courtesy of Goodyear

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Business

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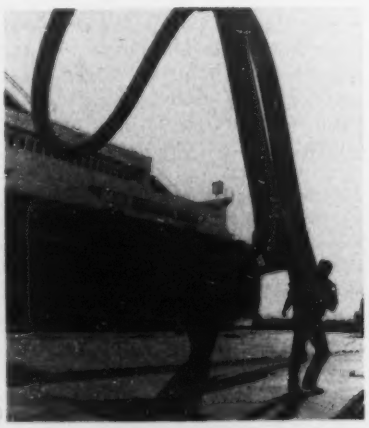
NMR studies of catalytic reactions in situ are providing clearer picture of mechanisms involved; animal rights groups mark laboratory animal liberation week; Texaco's new process for hydrogen has environmental advantages; catalytic dehydrogenation route to key alkenes offers product selectivity; solid-state rolling technique provides pinhole-free thin films from bulk polymer; cracking method is aimed at utilizing heavy hydrocarbons. **Page 25**

Education

Texas high school team wins first annual National Science Bowl in competition sponsored by Department of Energy and Intel Corp. Foundation. **Page 35**



Product Report

Forecasts for global rubber use indicate 1991 demand likely to be flat, but predict slow, steady rise in consumption next year and through 1995. **Page 37**

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LETTERS

First reported nanodes

To my knowledge the first electrode with atomic dimensions was reported by B. D. Pendley and H. D. Abruña from Cornell University [*Anal. Chem.*, **62**, 782 (1990)]. They were able to make and perform electrochemical measurements with a platinum ultramicroelectrode of an estimated radius of about 14 A, a width of just a few atoms of the metal.

Unfortunately, both the author of the article, "Electrodes a few atoms wide made at Caltech" (C&EN, Nov. 26, 1990, page 8), and the authors of the article referred to therein [*Science*, **250**, 1118 (1990)] overlooked the contribution reported in *Analytical Chemistry* last April.

Francisco A. Uribe
Los Alamos, N.M.

Polymer science education

The letter by Rudolf Faust (C&EN, March 18, page 3) claims that the polymer group at the University of Lowell was the earliest accredited B.S. program. Polytechnic University (then Polytechnic Institute of Brooklyn) started its Polymer Research Institute under Herman Mark in 1946. I would not step out on a limb and say that was the first one in the nation.

Helmut C. Neumann
Winchester, Va.

Professional esteem

As a graduate student in the last stages of my education, I feel compelled to respond to the attitudes that underlie a disturbing number of letters that appear in the pages of C&EN. Far too often problems are raised (including some that don't exist), but few solutions are suggested. Charles Krutchen's well-written letter (C&EN, Feb. 11, page 38) regarding the environmental movement's effectiveness in eliminating polystyrene foam containers from McDonald's restaurant chain served as the impetus for my response.

From these letters, it seems that chemists (including myself) are very self-conscious and possess low self-esteem when comparing ourselves to other professionals. As individuals, we fret over our diminishing pay scales relative to other professionals such as lawyers and medical doctors, as well at to other "less-learned" professions. Increasing, and more frightening, is the practice of complaining (or even joking) about the actions of ill-informed but powerful public lobby groups.

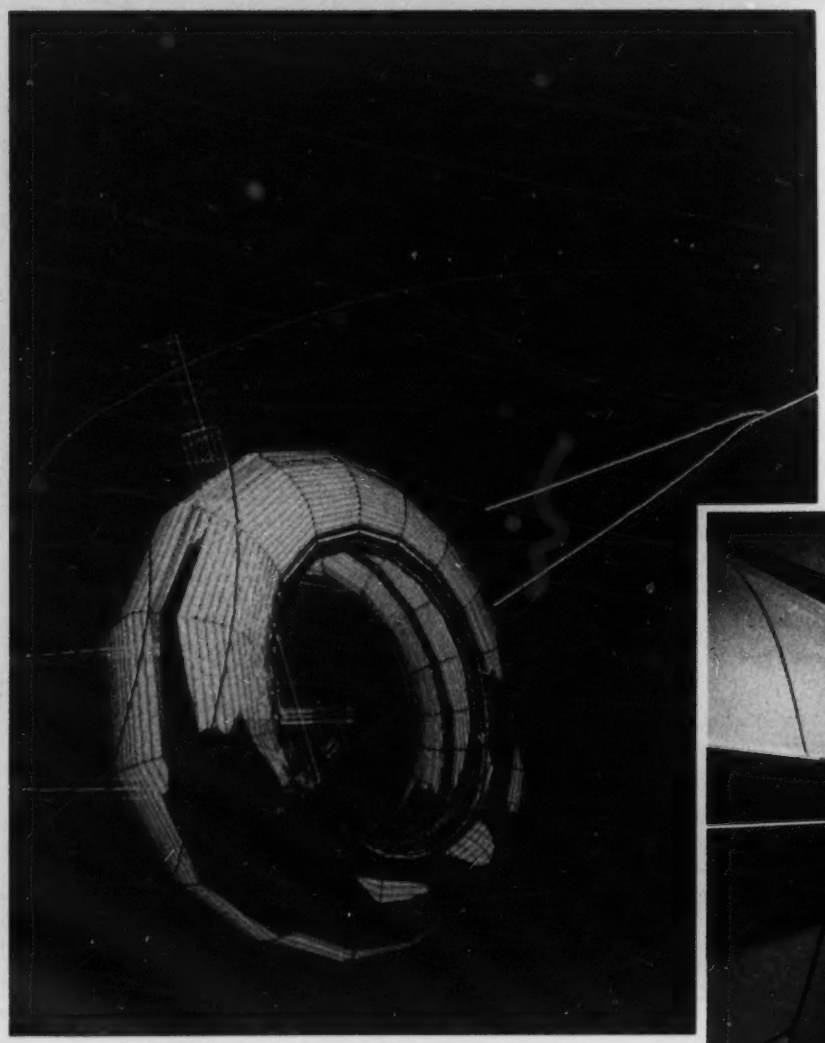
Please let me state outright that these issues are by no means trivial and they warrant the concern of all chemists. However, they are the symptoms of more serious problems: the lack of well-distributed information, and, unfortunately, our own apathy. The former is the result of the latter and it is up to each of us to correct the problems or put up with the consequences silently.

With regard to pay and professional esteem, I didn't enter chemistry for the money (although it would be nice to receive more), but rather for my love for the science. I didn't become a plumber, automechanic, or an attorney, because I wasn't interested. If my other undergraduate classmates chose not to enter chemistry because of the teaching methods of our professors, insufficient pay, or public recognition, then frankly they weren't all that interested to begin with. Slide shows and more cash would keep them longer, but not forever. It's never been a secret how well we're paid, but I'm certain that better teaching and an improved public image are things that we can and should improve upon.

The concerns of Krutchen, myself, and others are not completely unrelated to the reasons why students choose not to stay in chemistry. It was unfortunate that the polystyrene foam problems arose, but I think that given the magnitude of the solution taken by McDonald's relative to the overall scope of our industries, it may be the cheapest lesson we learn. Yes, there are justified environmental concerns and some outdated practices in the chemical industry that have (and will) come back to haunt us, but the false cry of the uninitiated should not go unheeded. We must be more careful, but more important in the long run, we must tell others about how careful we are, when they're misinformed, and when they're correct.

When you hear the loud minority of emotional but uninformed protesters/activists espouse incorrect or irrelevant facts, contact the source and the reporting media with the correct information. We seem to have enough effort to do so when a rate constant is reported that conflicts with our own work, or to shout when we aren't given credit in a paper's citations for our own work. If their concerns are justified, then work to fix the problem before we all look bad. The public doesn't care which of us is responsible; we're all chemists.

There is a Chinese proverb that states:



Computer analysis (left) of tire and vehicle suspension during actual driving conditions (below) help Goodyear engineers predict stress distribution on tires and auto body

Rubber Demand Is Expected To Grow after 1991

Bruce F. Greek, C&EN Houston

Until the major industrial economies of the world emerge from the effects of the current recession, growth in use of natural and synthetic rubber will remain minuscule. After growing modestly in 1990, global rubber demand this year is forecast to be flat, at 15.7 million metric tons. After 1991, it is expected that consumption of rubber will resume a slow, steady growth.

A slight decline in global consumption of synthetic rubber—10.4 million metric tons from 10.5 million metric tons used in 1990—is forecast for this year by the International Institute of Synthetic Rubber Producers (IISRP), whose statistical committee compiles data annually to predict rubber supply and demand.

Offsetting this decline, consumption of natural rubber will continue to grow globally but only 2%, to total less than 5.3 million metric tons. The net result is a small rise in total rubber consumption of 0.2%. Decreased use of both synthetic and natural rubbers will occur in Eastern Europe (including the Soviet Union) as those economies struggle for improvement, says William E. Tessmer, executive director of IISRP. In other areas of the world, rubber consumption is forecast to increase.

Growth in rubber consumption was modest in 1990, rising about 0.7%, according to IISRP estimates. Last year's rise in synthetic rubber consumption was smaller than that in natural rubber consumption. Synthetic rubber use grew less than 0.4% in 1990, while natural rubber use grew 1.3%.

The slow growth in demand for rubber has confirmed the maturity

Specialty rubbers developed for their special properties

Dozens of specialty rubbers are made around the world in volumes that are small to tiny when compared with the volume of styrene-butadiene rubber or polybutadiene rubber produced. Some of the materials are little more than laboratory curiosities, while others are produced at annual rates above 10,000 metric tons. Most are made in plants capable of making many variations of the basic elastomer, so only producers know the actual volume of these specialty rubbers. Examples of the specialty elastomers include:

Type/special properties

Acrylics
Resist high temperatures, chemicals, solvents, ozone, and light.

Butadiene-, carboxyl-, hydroxyl-, and halogen-terminated polymers
Are liquid to hard glossy polymers, with chemical and heat resistance.

Butadiene block and random copolymers, often with sytrene
Have elastomeric properties without vulcanization.

Epichlorohydrins
Have service temperature range of –65 to 300 °F., low gas permeation and good resistance to chemicals and solvents.

Ethylene copolymers with vinyl acetate, ethyl acrylate
Retain tensile strengths over wide range of temperatures, have good weatherability and good oil resistance.

Fluorinated elastomers, polymers of fluorinated ethylene, propylene, vinylidene
Resist heat, flame, chemicals, and have good weatherability.

Polyethylene-modified chlorine or sulfur and chlorine
Resist ozone, heat, chemicals, oil, and flame, and have operating range of –65 to 300 °F.

Polyisobutylenes
Have good weatherability, good electrical properties, and low gas permeability.

Polyester/polyether polymers
Have service range of –65 to 275°F and high resilience with good resistance to chemicals, oils, and solvents.

Polynorbornenes
Can be highly loaded with oil and fillers; have good dynamic properties and low hardness.

Polyolefin thermoplastic polymers
Have good elastomeric properties without vulcanization; can be reprocessed, and can be modified to allow a wide range of properties.

Propylene oxide-allyl glycidol ether copolymers
Have service range of –77 to 300 °F, excellent resilience and hysteresis, and moderate resistance to oil and solvents.

Silicones and fluorosilicones
Have service range of –150 to 600 °F, excellent resistance to ozone and weather, and good electrical properties.

Sulfide polymers from various organic sulfides
Resist oil and solvents, have good aging characteristics, and low gas permeability.

Urethanes from polyesters, polyethers, and diisocyanates
Are available as either thermoplastic or curable polymers, have high tear and abrasion resistance, good oil, solvent, and ozone resistance, moderate to good low-temperature properties. Cured polymers have good tensile strength and moderate heat resistance.

Source: International Institute of Synthetic Rubber Producers

of this global industry. Growth in demand generally will continue to be low: The IISRP committee forecasts that world demand for rubber will grow only 2.1% annually between 1991 and 1995, with most of the progress occurring after 1991 because of current slowdowns in the automobile and construction industries. By 1995, global use of rubber is expected to reach 17.3 million metric tons, split between synthetic rubber at 11.2 million metric tons and natural rubber at 6.1 million metric tons.

Growth in synthetic rubber use in the future will vary from region to region, according to IISRP data. In North America (Canada and the U.S.), the consumption growth rate will average 2.4% annually between 1991 and 1995, reaching more than 2.8 million metric tons. In Western Europe, Africa, and the Middle East, growth will average 2.0% annually. In Latin America (Mexico and south), synthetic rubber consumption will increase 19% over five years, or 3.5% annually, but from a smaller base of slightly more than 500,000 metric tons. In the Asia/Oceania area, which excludes centrally planned economy countries such as China, the consumption growth rate will average 3.0% annually (spurred in part by increased auto and tire production) and is expected to exceed 2 million metric tons in 1995.

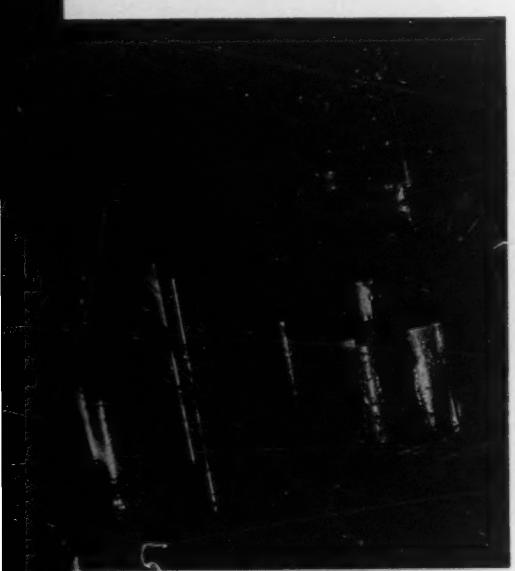
Market share of the various synthetic rubbers will change to a limited extent. Styrene-butadiene rubber (SBR), in the noncentrally planned economies, will have a consumption increase of more than 260,000 metric tons, to greater than 2.9 million metric tons in 1995. This tonnage will account for about 38% of the total use of synthetic rubber, roughly the same market share that SBR had in 1990. Polybutadiene, the second largest elastomer consumed in areas outside the centrally planned economies, will have 16.6% of the market, likely growing fast enough to hold its share in 1995. In 1991, carboxylated SBR latex consumption will exceed polybutadiene use for the first time and should remain in slightly greater demand through 1995.

Other, smaller volume rubbers are experiencing notable growth. Ethylene-propylene elastomers, the

growth pacesetter of recent years, will continue to lead with an average annual increase of 4.1% through 1995. Nitrile rubber consumption is expected to hold second place among nonspecialty elastomers, averaging 3.7% annually. Other synthetic rubbers, of which butyl, polychloroprene, and polyisoprene account for a vast majority of the total, will grow more slowly than the larger volume synthetic rubbers.

Thermoplastic elastomers (TPEs) are growing faster than the basic elastomers. They consist of a large number of products considered to be derivatives of other elastomers. The IISRP places TPEs "below the line" as an item in its long-term forecast, says Tessmer. Use of TPEs is projected to expand from 613,000 metric tons in 1989 to 883,000 metric tons in 1995, at an average annual growth rate of 6.3%.

Tires and tire products, traditionally the largest use of rubber, will continue in the lead through 1995 and beyond, according to the current forecast. Tires and tire products are expected to account for more than 61% of total new rubber consumption in 1995. About 51% of all synthetic rubber produced will go into tires and tire products, along with slightly less than 75% of natural rubber production. As in the past, roughly two thirds of SBR and polybutadiene consumption will be in tires.



Rubber cushion for auto drivetrain leaves Goodyear assembly line

Production of automobile, truck and bus, and farm equipment tires outside the former East bloc was about 690 million tires in 1988, according to William W. Barbin, manager, compound technology at Goodyear Technical Center, Akron. In addition, aircraft and various kinds of off-the-road tires were made in relatively small numbers. Of the 690 million tires, about 40% went to markets in North America, 29% to Europe, 24% to Asia and Africa, and 7% to Latin American, Barbin told attendees of the International Rubber Study Group (IRSG) in Ottawa, Canada.

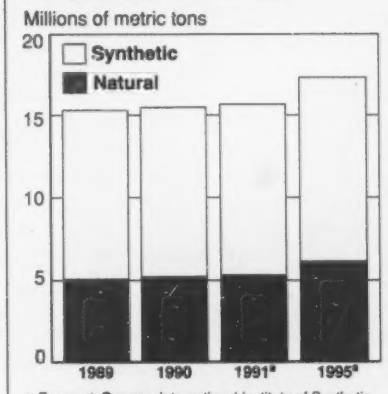
The faster growing types of tires in North America, says Barbin, are those designed for high performance and for all-season operation. High-performance tires require more elastomer in their manufacture because their designs call for larger diameters and lower aspect ratios and because the hard wear such tires usually receive shortens tread life.

The U.S. passenger car tire market becomes increasingly affected by new-vehicle gasoline mileage requirements. Barbin estimates lowered tire-rolling resistance will contribute only 0.5% of an 18% increase expected in the average fleet gas mileages of carmakers. Nevertheless, this potential share in improving average fuel consumption looms as an important factor in winning original equipment markets.

The kind of polymer in the compound of elastomer, carbon black, silica, and other chemicals used to make a tire can have a significant effect on its rolling resistance, says Barbin. To determine this characteristic, the hysteresis of a compound is tested over a range of temperatures. Polymer engineering then is used to produce a best balance between traction and rolling resistance for the tread compound.

As a result, Barbin expects changes in synthetic rubbers will continue. Additional different solution SBRs will come to market, as will numerous new specialty polymers. The halobutyl elastomers likely will be used more and more in tires. Other elastomers—emulsion SBR, nitrile, and polyisoprene—are expected to have stable markets, while ethylene-propylene diene monomer rubber (EPDM) will grow only if it is cost/performance competitive.

Slow growth expected for global rubber use



a Forecast. **Source:** International Institute of Synthetic Rubber Producers

Tires accounted for 61% of the more than 7 million metric tons of synthetic rubber consumed in 1990, according to estimates of the IISRP. Of the remaining consumption, another 10% went to automobile mechanical goods, such as belts, hoses, and gaskets. This category includes replacement parts, just as consumption of rubber in tires includes replacement tires.

Automotive mechanical goods often are made of specialty elastomers, selected for their abilities to meet such stress conditions as the higher temperatures now encountered in engine compartments—a result of efforts to reduce polluting emissions and increase mileage. This area of synthetic use, because of its size, spurs developmental efforts in new elastomers and on modification of existing elastomers to allow them to be specified for use in automotive mechanical goods.

Another large use of synthetic rubber is in making mechanical goods for nonautomotive applications. These rubber products cover a wide variety of belting (including conveyer belts), of hose for many types of service, and of other fabricated products. About 650,000 metric tons of synthetic rubbers were used in such products last year, almost as much as went into mechanical goods for automotive uses.

Smaller use areas include modification of various thermoplastics,

usually to impart shock resistance; footwear, largely shoe and boot soles; construction, mainly roofing material and pond lining; wire coverings, especially for services where plastic wire covering doesn't perform well; and adhesives of many kinds. As a group that includes other smaller miscellaneous applications, these uses account for more than 20% of synthetic rubber consumption.

Outlook varies widely; some uses continue to have high growth rates while others are declining. The nonautomotive uses are growing faster than the tire and tire product uses, but from a smaller base. And such uses are expected to have less effect on the total rubber demand than will tires, especially if high-performance tire use increases rapidly and if vehicle speeds continue to increase.

SBR is the most widely used synthetic elastomer. As a result, SBR is the elastomer by which all new polymers are judged. In the past, SBR was produced in larger quantities in the U.S. than are produced now. In 1973, SBR's peak year, output was nearly 1.37 million metric tons. At 807,000 metric tons last year, output was off more than 40% from the high of 1973. Yet, that output was well above the production of 692,000 metric tons in 1985, the lowest in recent history.

Available capacity has followed the trend in production decline. At the end of World War II, U.S. capacity to make emulsion SBR was 850,000 metric tons, Terry J. Renninger, president of Firestone Synthetic Rubber & Latex, a division of Bridgestone/Firestone told the IRSG meeting. By 1973, U.S. capacity totaled almost 1.4 million metric tons. Since then, capacity has contracted to 881,000 metric tons, close to the 1945 capacity. The U.S. capacity is close to the 776,000 metric tons of Western Europe and to the 882,000 metric tons of Asia. Africa has one plant with 40,000 metric tons of capacity, and Latin American has about 379,000 metric tons of capacity. That is a capacity total of slightly less than 3 million metric tons. Another 1.8 million metric tons are available in the centrally planned economy countries, Renninger says. And there is 576,500 metric tons of solution SBR capacity outside the centrally planned economies, but no estimate of capacity in those countries is available.

Outside the centrally planned economies, capacity totals about 3.5 million metric tons, but demand last year was about 2.5 million metric tons, Renninger estimates. Hence, the projection is that competition will remain fierce. Some capacity may be closed. But despite the apparent overcapacity, a significant number of SBR plants, of either emulsion or solution processes, are planned worldwide. Renninger cites IISRP-compiled lists that show plans for one expansion in Western Europe, one in North America, two in Latin America, three in the Middle East/Africa region, and four in Asia/Oceania. If specialized types of SBR, such as latex and TPE are included, the number of new projects rises to 42. It is unlikely that all of those proposed plants will be built, but many will.

Although solution SBR technology allows much greater control of polymer structure than is obtained from emulsion technology, Renninger forecasts that emulsion SBR production will continue well into the next century. Giving reasons, he notes the plants are in place and, in general, are fully depreciated. Worldwide overcapacity will cause continued price pressures that will lead marginal producers to retire some of their capacity. With low margins characteristic of such situations, plant modernization and new product development become more difficult to justify.

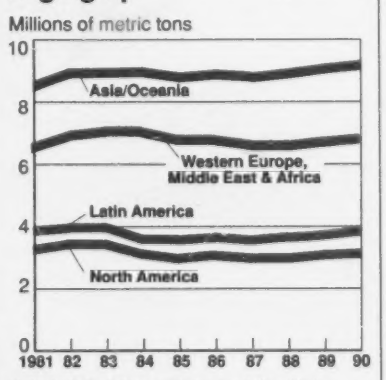
Renninger also expects solution technology will become widespread. As it does, producers will emphasize more products designed to meet specific customer needs. Such polymers will be less sensitive to competition, thereby allowing the producers better margins.

The shift toward solution technology for SBR must not be taken too far, Renninger cautions. For example, emulsion technology may produce polymers not easily made when using solution technology. In the solution process as polymerization proceeds, changes in the monomer composition will alter the polymer composition along the chain so that all of the polymer chains will have the same composition. In the emulsion process a similar variation of monomer composition results in polymer chains made with a differing composition, one that is dependent on the monomer composition at the time the specific chain is produced. With the emulsion process, therefore, the result is an in-situ

Goodyear photo

Worker checks synthetic rubber dock fenders at Texas seaport

Synthetic rubber capacity is edging up



Note: Includes latices; excludes specialty rubbers.
Source: International Institute of Synthetic Rubber Producers

blend of polymer chains of varying composition. Such a blend would be very expensive to make using a solution process, says Renninger.

Another advantage that emulsion technology retains is that many more monomers can be polymerized in it than can be done in solution. If this capability were applied to new concepts unfolding in polymer special end-group solution technology, some unique polymers might be developed that could offer lower rolling resistance in tires. Although the product line of emulsion SBR has changed little over the past 25 years, it would be foolhardy to assume that no new breakthroughs will occur, Renninger points out.

Tires will continue to dominate use of SBR. About 75% of U.S. consumption of SBR currently goes to tires. An additional sizable quantity (about a tenth that of tire use) goes into automotive mechanical goods, for a combined total automotive use of more than 80% of consumption.

Tire use of SBR depends on several properties that provide slightly better cost/performance results than either natural rubber or polybutadiene rubber. (Blends of these elastomers, however, generally are used in tires to obtain the best overall cost/performance/processability). SBR has good abrasion resistance (lower tread wear). It is not so good as polybutadiene but is better than natural rubber. SBR also resists crack and cut growth better than either natural rubber or polybutadiene. A problem of lower tack and low green (unvulcanized) strength with SBR has long been overcome by use of various hydrocarbon resins known as tackifers.

A reversal of the decline in demand for SBR now seems possible, as drivers' demands change. In the 1970s and 1980s, automobile production declined, reducing original equipment demand. At the same time, imports of tires for the replacement market, as well as for imported cars, further reduced U.S.-made tire demand. Downsized cars led to smaller tires containing less elastomer. The shift from bias-ply to radial-ply tires more than doubled tread life and required much larger quantities of natural rubber in the tires' carcass and sidewalls. All of those developments reduced SBR consumption and led to plant closings.

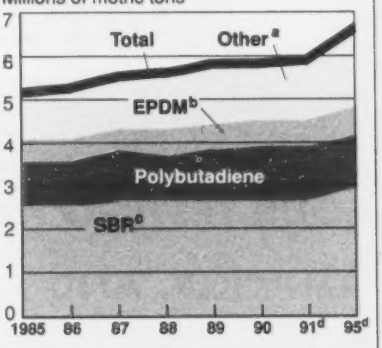
Nontire uses of SBR, at about 25% of consumption, still depend on the automotive industry for about a third of this use category. While a majority of the SBR is used in auto mechanical goods without blending, the trend is toward more blends with EPDM and nitrile rubber. The remainder of SBR uses are mechanical goods such as industrial hose, belting, cable coverings, gaskets, and footwear. Use of SBR in this large miscellaneous group slips slightly each year as performance requirements cause some replacement by other elastomers, especially EPDM. When natural rubber costs significantly less, it also will be substituted for SBR.

Long term, the outlook for SBR appears to be slow growth, probably at an average of 1% annually. Price competition from natural rubber looms as the largest factor limiting SBR growth. Automobile production and imports of tires, especially for passenger cars and light trucks, are next in importance as an influence on growth. Because the solution process provides polymers with more linear configuration and with better control over molecular weight distribution than does the emulsion process, solution SBR could account for most of the future growth as producers work to provide the best possible elastomer for customers.

Natural rubber, the major competitor of SBR, has had erratic growth in U.S. consumption. Since 1980, however, natural rubber consumption has grown every year until 1990, when it declined 3.2% to 839,000 metric tons of both dry rubber and latex, according to data compiled by the Rubber Manufacturers Association (RMA). In 1991, consumption of natural rubber in North America is forecast by IISRP to slip slightly (0.4%), following a 5% decline in 1990. The same reasons for a decline in consumption of SBR will cause the decline in natural rubber.

Consumption of natural rubber mirrors SBR use, with 75% going

SBR share of rubber output slides



Note: Excludes production in centrally planned economy countries (Albania, Bulgaria, China, Czechoslovakia, the former East Germany, Hungary, North Korea, Poland, Romania, U.S.S.R., Yugoslavia, Vietnam) and excludes carboxylated latices. **a** Includes butyl, nitrile, polychloroprene, polyisoprene, and miscellaneous. **b** Ethylene propylene diene monomer rubber. **c** Styrene-butadiene rubber both solid and latex forms. **d** Forecast. **Source:** International Institute of Synthetic Rubber Producers

Uneven growth forecast for rubber demand

	Synthetic rubber				Natural rubber				Total rubber
	Thousands of metric tons			Average annual change, %	Thousands of metric tons			Average annual change, %	Average annual change, %
	1990	1991	1995	1991–95	1990	1991	1995	1991–95	
North America	2,523	2,541	2,842	2.4	909	905	990	1.7	2.2
Western Europe, Africa, Middle East	2,243	2,294	2,471	2.0	1185	1200	1258	1.2	1.7
Asia/Oceania	1,771	1,790	2,052	3.0	1864	1925	2340	4.7	3.9
Latin America	536	553	637	3.5	258	271	314	4.0	3.7
Eastern Europe[a]	2,999	2,848	2,680	–2.2	310	290	400	5.2	–1.4
CEPC—China/Asia[b]	380	403	508	6.0	630	668	843	6.0	6.0
TOTAL	10,452	10,429	11,190	1.4%	5156	5259	6145	3.6%	2.1%

a Includes Albania, Bulgaria, Czechoslovakia, the former East Germany, Hungary, Poland, Romania, U.S.S.R, and Yugoslavia. b Includes the centrally planned economy countries of China, North Korea, and Vietnam. **Source:** International Institute of Synthetic Rubber Producers

into tires and retread rubber. The share of natural rubber going into passenger car tires increased over the past decade at the expense of the share going into truck and bus tires because of the rapid shift toward radial-ply design passenger car tires. Natural rubber gets the nod for more use in radial tires because of cost; tire building needs; and flexibility, resilience, and aging stability, all of the properties wanted in tires.

Nontire uses of natural rubber include a 5% share in automotive mechanical goods. Natural rubber often is blended with synthetic elastomers to gain better weathering properties. Nonautomotive mechanical goods account for about 10% of natural rubber consumption and include most of the same applications into which SBR goes.

Natural rubber latex use has been growing rapidly, even while carboxylated and noncarboxylated SBR latices have replaced it in carpet foam. The driving force behind growth of natural rubber latex is in making dipped goods, namely, balloons, surgical and examination gloves, and condoms. The AIDS concern prompted a surge in output of gloves and condoms, which is forecast to continue in the U.S. and spread throughout the world.

Outlook for natural rubber demand depends heavily on pricing, with performance critical in certain applications. Since tires account for about 75% of U.S. consumption, changes in tire demand most directly affect growth. On balance, the forecast growth in use of natural rubber after 1991 will stem from the net effect of such factors as a shift toward slightly larger cars (which will require larger tires, at least until higher fuel economy standards are in place), higher road speeds, net of tire imports over exports, increased construction work to rebuild the country's infrastructure, and tires for large aircraft in operation.

Polybutadiene, another important competitor of SBR, ranks second in output, if carboxylated SBR latex is excluded. This elastomer became commercially available in 1961. Its production rose steadily until the mid-1970s and has been erratic, but generally upward ever since. Output reached its highest level in 1989, at 411,485 metric tons, and declined to 403,388 metric tons in 1990, according to RMA data. Excluding centrally planned economy countries and Eastern Europe, global consumption of polybutadiene is forecast to grow to more than 1.3 million metric tons by 1995, up from less than 1.2 million metric tons in 1991, according to IISRP data. The vast majority of production is solution process; small but unknown quantities of emulsion process polybutadiene are made in various parts of the world.

Because it has good resistance to abrasion, polybutadiene primarily goes into tire treads. Lesser amounts go into carcass and sidewall components, where its flexibility and resilience tend to keep down heat buildup. Wet-skid resistance of polybutadiene is poor, so it is blended with SBR or natural rubber for use in a compromise performance situation.

At about 1.5% annually after this year, the outlook for growth in polybutadiene demand for use in tires calls for only a slightly better performance than will occur for SBR. The relatively low growth track for polybutadiene and SBR will be caused by the same tire-related factors—small increases in tire production, slightly larger tires for increasing numbers of luxury and performance cars, and the continuing shift of truck and bus tires toward the radial-ply design.

Tires dominate global synthetic rubber use

1990 consumption = 7.1 million metric tons

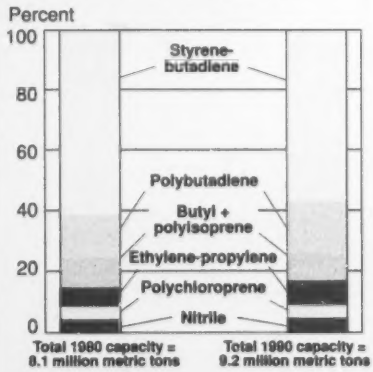
Source: International Institute of Synthetic Rubber Producers

The future impact on polybutadiene by solution process SBR and the more recently developed polymers, such as 1,2-butadiene, is less certain. (Conventional polybutadiene uses the 1,3-butadiene monomer.) Solution SBR could partly replace polybutadiene in tread rubbers. Tests show it provides less tread wear, better skid resistance, and lower rolling resistance. If a significant shift in tread elastomer composition develops, growth for conventional polybutadiene could fall from the current forecast rates.

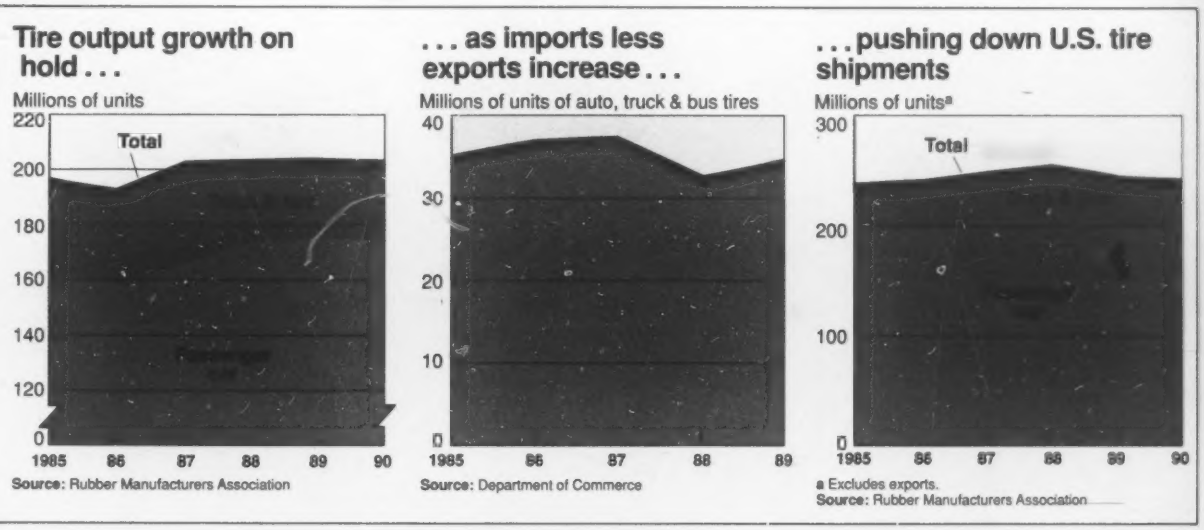
Nontire uses of polybutadiene fall into two categories. About 20% of U.S. consumption goes to modify plastics, such as polystyrene and acrylonitrile-butadiene-styrene (ABS) resins, to give improved impact resistance. There are many variations in how the elastomers are made (depending on their effects on the desired properties in the modified polymer), such as composition of the plastics, and desired properties of the polybutadiene used. Sometimes, the modified resins are alloyed with other plastic resins for specialized applications.

A small amount of polybutadiene goes into various kinds of mechanical goods, some of which are used in the automotive industry. These mechanical goods are similar in form to those made by using other elastomers. Examples are belts of various kinds, hoses, gaskets, seals, and wire covering. An exception is the

Capacity for smaller volume rubbers grows



Note: Smaller volume rubbers include latices but exclude specialty rubbers. Capacities do not include those of Albania, Bulgaria, China, Czechoslovakia, the former East Germany, Hungary, North Korea, Poland, Romania, U.S.S.R., Yugoslavia, or Vietnam.
Source: International Institute of Synthetic Rubber Producers



centers for golf balls, which is a small use. Growth in these mechanical goods is expected to be slow and, because these uses are so small, will have a negligible effect on total consumption.

When commercial production of EPDM blossomed, some of its proponents claimed it could be a serious competitor in the tire elastomer market, possibly replacing other synthetic elastomers. While its use as a major tire rubber didn't work out, EPDM has had its uses broadened rapidly and has become a major-volume synthetic elastomer, ranking third in U.S. production. In the past, demand for EPDM became erratic because of the effects of recessions. Demand growth increased at an average annual rate of about 4% during the 1980s. Output in 1990 slipped to 256,000 metric tons, the second minor drop since the peak production year of 1988 when it reached 263,000 metric tons.

Production curtailments, as a result of maintenance and other plant interruptions and ethylene supply limitations, had some impact on EPDM output beginning late in 1988 and lasting until early 1990. Several capacity additions were made in 1989 and 1990, as ethylene supply improved, and more capacity will be available at midyear. In June, Uniroyal Chemical will complete its latest round of expansion at its plant in Geismar, La., to bring the total capacity at that site to about 90,000 metric tons per year. This third production unit at Geismar comes on stream more than 25 years after initial production began in a single, smaller unit that has since been debottlenecked several times.

By midyear, U.S. capacity for EPDM elastomers will be about 325,000 metric tons. Additional capacity at the plant sites of some companies produces ethylene-propylene copolymers. These elastomers account for 10 to 20% of output, estimates an industry source. If demand for EPDM grows very slowly, similar to demand growth for other synthetic elastomers this year, output could hold at about 260,000 metric tons, allowing the in-place capacity to be operated in the 80 to 85% range.

After acknowledging a supply problem for EPDM in 1989 and 1990, Daniel A. Shantz, business manager for EPDM elastomers at Uniroyal Chemical, says no supply tightness will occur for at least two years and probably not for four. Growth in consumption of some uses of EPDM will be quite large, as high as 7% annually, when compared with other tire elastomers. The overall growth will vary between 3 and 5% through 1995.

Tires accounted for less than 3% of EPDM consumption last year, with the rubber going mostly into white strips and raised white letters on tire sidewalls and to use as a blend with butyl elastomers in tubes. Other automotive uses, 17% of total use, went to mechanical goods, hoses, weather stripping, gaskets and seals, and other parts. Many of these products are blends of EPDM and thermoplastic elastomers, says John R. Johnson, Uniroyal Chemical's plastics products development manager. Some of the newer applications of blends are with thermoplastic olefins in the covers for bumpers and with thermoplastic vulcanates for wire coverings.

Those uses in mechanical goods continue to expand use of EPDM in blends because of cost/performance developments, says Johnson. Fabrication advantages help, by allowing fast injection molding and rapid curing to give high part production rates.

Future developments could carry over to other uses. For example, EPDM can be blended with engineering resins, such as nylons, for a wide variety of applications, Johnson points out. Other blends could include polycarbonates and polyesters.

It's the nonautomotive uses of EPDM that are growing fastest, says Uniroyal's Shantz. Single-ply roofing may be maturing, but after the construction slump of this year is over, this use could grow 6 to 7% annually, he forecasts. As the largest single use of EPDM, roofing will take about 50,000 metric tons this year, he estimates. By 1995, this use could require about 65,000 metric tons of EPDM. Competition from other forms of single-ply roofing limits the growth of EPDM in this use. The major competitors are polyvinyl chloride and other thermo-

plastics, and asphalts that are modified by styrene block copolymers or by the atactic form of polypropylene. These modified asphalts are impregnated on fiberglass or polyester fabrics to make roofing material. In this use, EPDM dominates but is less than two thirds of the total.

Other important end uses of EPDM include wire and cable insulation, hose (other than for automobiles), components for both household and institutional appliances, sheet materials for such uses as pond liners, and many kinds of gaskets and seals.

A major use of the ethylene-propylene copolymers is in viscosity index additives that are designed to improve the viscosity of lubricating oils as temperatures change. This use of these elastomers is generally considered to be outside of the usual automotive categories involving tires and mechanical goods. The competition from styrene block copolymers and polymethyl methacrylates, does not, because of their cost, eclipse ethylene-propylene copolymers as the greatest use. Growth in this use is promoted by having more vehicles in operation and by a current trend toward higher quality lubricating oils for smaller engines. Such engines are stressed more for increased output. Growth is offset by the trend toward longer intervals between oil changes for newer cars and more use of partially or entirely synthetic oils.

Exports account for a large share of U.S. production of EPDM, more than 28% last year, when exports rose to almost 73,500 metric tons, according to RMA statistics. Imports declined drastically in 1990. They dropped from more than 32,000 metric tons to more than 19,000 metric tons last year. The surge in imports of EPDM occurred in 1988 and 1989 when U.S. output was restricted. Exports are expected to continue to rise this year, especially to Europe and the Far East, says Shantz.

Nitrile elastomers are the only other rubber with production data broken out by the RMA. Last year, production of the various nitrile elastomers was more than 56,200 metric tons. Exports exceeded imports slightly, apparently making consumption about 53,500 metric tons. The peak year for nitrile production was 1974, when the total of dry and latex forms was almost 88,000 metric tons. Global consumption of nitrile elastomers and latex, outside the centrally planned economy countries, will total 249,000 metric tons and will rise to 290,000 metric tons by 1995, according to IISRP.

Both U.S. and world capacity to make nitrile elastomers is more than sufficient to meet demand, says Vincent P. Rooney, business manager for nitrile elastomers at Uniroyal Chemicals. Demand has fallen slowly over the past 15 years because of downsizing of cars, the rise in imported cars, and competition from specialty elastomers, he notes.

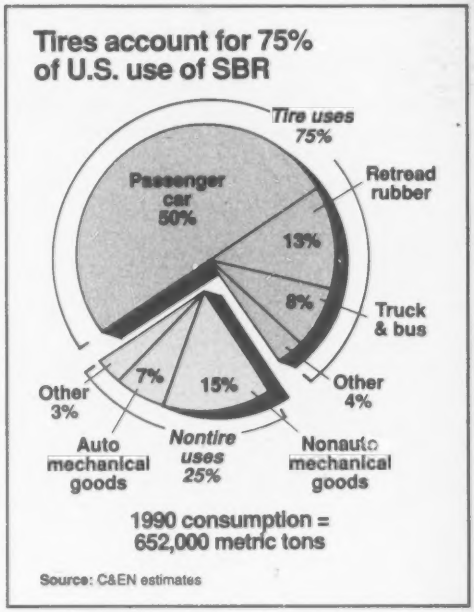
Capacity for some U.S. producers is flexible because it is a part of the design of SBR plants. Polymerization by the emulsion process is quite similar to the process for SBR. As a result of flexible capacities, output could be adjusted to meet needs should a possible resurgence occur in demand for nitrile rubbers.

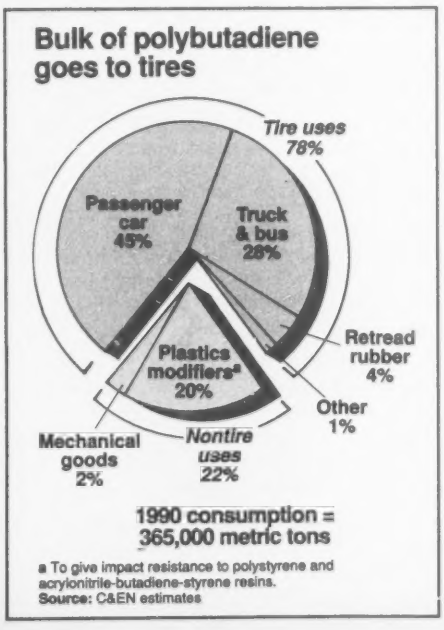
Nitrile's high resistance to hydrocarbons over a wide temperature range is what prompted its first commercial production prior to World War II. A higher concentration of acrylonitrile (the comonomer is butadiene) generally improves this resistance, while lower concentrations produce elastomers with better resilience.

Because of nitrile's oil resisting properties, automotive mechanical goods account for more than half of nitrile's consumption, including some use as wire and cable insulation and for impact modification of polyvinyl chloride and ABS resins. These modified resins go into automobile body parts, such as weather stripping, insulation, and kick panels. Nonautomotive uses cover a wide variety of products. Mechanical goods for oil-well drilling and production equipment use more than 10% of consumption, says Rooney.

After this year, growth in demand for nitrile elastomers will be in the 2 to 3% range in the U.S. and in the 4 to 5% range on a global basis, Rooney says. Automotive uses are expected to grow slowly because of competition from other elastomers. Most of the remaining uses will reflect the growth in gross national product.

Numerous other elastomers are produced in varying quantities, with production reported only as a total because of disclosure problems. Some of these, such as butyl, polyisoprene,




Bulk of polybutadiene goes to tires
Tire uses 78%
Passenger car 45%
Truck & bus 28%
Retread rubber 4%
Plastics modifiers[a] 20%
Other 1%
Mechanical goods 2%
Nontire uses 22%
1990 consumption = 365,000 metric tons
a To give impact resistance to polystyrene and acrylonitrile-butadiene-styrene resins.
Source: C&EN estimates

polychloroprene (neoprene), silicone, and polyurethane elastomers, are produced in large quantities. Production of this group in 1990 was more than 546,000 metric tons, off substantially from the 647,000 metric tons produced in 1989, according to RMA data. Global consumption, excluding the centrally planned economy countries, is forecast to be 1.2 million metric tons this year, according to IISRP. Growth on a global basis will be higher than for SBR because rising performance expectations lead to more demand for the specialty elastomers.

Many of these other elastomers have special niches which consume large shares of total use. For example, butyl elastomers, including the halogenated butyls, go mainly into tire carcass inner liners and tubes because of the elastomers' air impermeability. Polychloroprene elastomers, noted for their resilience and resistance to ozone and weathering, go almost entirely into mechanical goods. Polyisoprene most nearly duplicates natural rubber, so it competes on price, quality, and uniformity for the same tire and nontire uses as natural rubber.

Another large-volume rubber—carboxylated SBR latex—had production of more than 465,000 metric tons in 1990, according to data compiled by the consulting firm Ernst & Young for the Committee on Resin Statistics of the Society of the Plastics Industry. Noncarboxylated SBR latex is included with SBR data by RMA. IISRP estimates 1991 consumption of carboxylated SBR by Eastern Europe and China, North Korea, and Vietnam to be about 1.2 million metric tons.

About half of the carboxylated SBR latex goes for coatings of paper, particularly those which are heavily pigmented for glossy printing uses. Paper coating uses are forecast to continue to grow at above the gross national product rate. Consumers have a limited ability to switch to a competitor, polyvinyl acetate, based on prices.

More than a third of this latex consumption goes into carpet backing as a laminating adhesive to hold the fiber tufts to polypropylene or to jute backing. It also is used as backing material in unitary-back carpets. Growth in SBR latex will be affected by technological improvements that will reduce the amount of latex needed per unit area of carpet and by increases in home and commercial building that will increase demand for carpet.

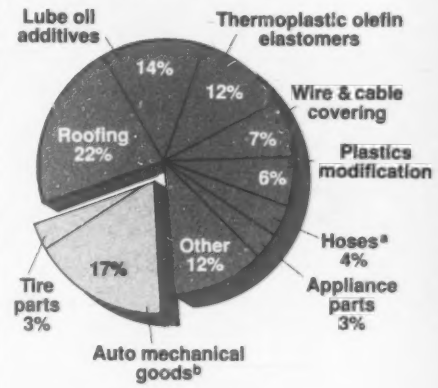
A large number of specialty elastomers are used commercially. Data are not available on their individual production and consumption, either because of the small size or because some may not be included in all the other categories by either RMA or the U.S. Department of Commerce. Some of these specialty elastomers are consumed, but not produced, in the U.S. Imports account for their supply, sometimes less than 1 million lb per year.

Some of the specialty elastomers are made and consumed in greater quantities than are nitrile elastomers. For example, polyurethane elastomers likely were consumed at nearly 150,000 metric tons last year because automotive use boomed as carmakers worked to reduce weights of autos and to improve trim components. Consumption of silicone elastomers is estimated to have reached 50,000 metric tons last year. The styrenic thermoplastic elastomers seems to have neared 150,000 metric tons consumption last year. In contrast, polynorbornene elastomers and propylene oxide-based elastomers each had less than 1 million lb, or under 500 metric tons, consumed in the U.S. last year.

Polyurethane elastomers and raw materials are available from several suppliers, some of whom specialize in areas such as microcellular, cast, and millable gum products plus thermoplastic elastomers. A wide range of fabricated products are made of polyurethane elastomers.

Reaction injection molding (RIM) technology is used to produce more than half of the products made from polyurethane elastomer. It is likely the technology will take a growing share of the total because of rapid demand growth in the automotive industry. Nearly all of the automotive consumption is in body parts, particularly bumpers and related trim parts and window frames. Growth in the automotive field could be accelerated if structural reaction injection molding (SRIM), involving fiber reinforcements, becomes a high-speed process, permitting larger body parts to be made. There is competition from other plastic materials based on unsaturated polyesters, for example. Growth in these uses will be cyclical, depending on public acceptance of plastic auto body parts and on automakers' views of costs of such parts. Overall, the growth could range between 3 and 5% annually in the 1990s.

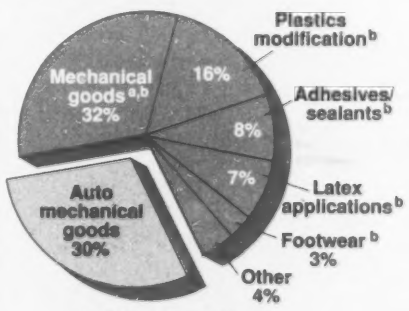
Nonauto uses dominate EPDM consumption



1990 consumption = 196,000 metric tons

Note: EPDM = ethylene propylene diene monomer rubber. **a** Excludes automotive hoses. **b** Includes hoses, weather stripping, window seals, and bumper covers. **Source:** C&EN estimates

Low-volume nitrile goes to diverse uses



1990 consumption = 54,000 metric tons

a For industrial, mining, and oil-field applications, and weather stripping. **b** Nonautomotive use. **Source:** C&EN estimates

Other RIM products are made for uses outside the automotive industry, such as in office machines, sporting goods, furniture, and other consumer products. Heat shields for copy machines and satellite dishes are SRIM products. Acceptance of RIM urethane elastomers outside the automotive industry requires much technical service by suppliers. Once accepted, however, the use grows rapidly. Outside the automotive industry, these uses of urethane elastomers could grow 5 to 7% annually.

The other forms of urethane elastomers go into more specialized uses. Non-RIM microcellular material goes mainly into high-performance soles for military and sporting boots, the growth of which will be low. Cast elastomers go into many kinds of industrial wheels, electronic product encapsulation, and mechanical goods. Growth of cast materials will depend on industrial and mining growth and is forecast to be low. Millable gums are difficult to process so are used in small quantities in industrial uses where toughness is desired. TPEs account for less than a quarter of polyurethane elastomers. They go into automotive mechanical goods, hoses, adhesives, recreational products, and many other consumer products. These elastomers face competition from plastics and other rubbers, so their growth is forecast at about GNP growth.

Output of silicone elastomers totaled almost 52,000 metric tons in 1989, according to the estimate of the U.S. International Trade Commission. This reported production could be high because fillers and reinforcing agents may have been included. The term silicone elastomers includes fluorosilicones as well as various hydrocarbon-substituted forms. The same plants are used to make silicone fluids and resins as well as elastomers, so capacity is quite flexible.

About two thirds of these elastomers are cured at room temperature; the remainder require heat. Although silicone elastomers have high resistance to hydrocarbons, ozone, and weathering, they have low strength. Therefore, compounding is critical in most applications; compounding technology combines art and science to produce numerous proprietary elastomers.

Almost half of the heat-cured types of silicone elastomers go into automotive applications, say Kevin M. Byrne, business manager for heat-cured rubbers at General Electric's Silicone Products Division. Another 25% goes to wire and cable covering other than for automotive use. Medical applications, largely tubing, are about 10%.

Growth should be 5 to 7% annually, says Byrne. The Clean Air Act will spur automotive uses. Parts for various durable items also will grow once the recession is over. Blends with other materials hold significant potential because they are a means of reducing costs while maintaining performance.

Sealants and adhesives of many kinds account for about half of silicone elastomer consumption. Many of these uses are in the construction industry where adhesives may be used with extruded silicone elastomers. Other uses are in various electronic and electrical devices either as adhesives or as encapsulating and cushioning agents. These uses are forecast to account for most of the increased future demand.

Many kinds of TPEs are commercially available. Global demand outside the centrally planned economy countries will reach nearly 700,000 metric tons in 1991, according to IISRP. Strong growth in TPEs is also forecast, with consumption at more than 880,000 metric tons in 1995. Consumption in Canada and the U.S. in 1991 will be 278,000 metric tons, about 10% of the total.

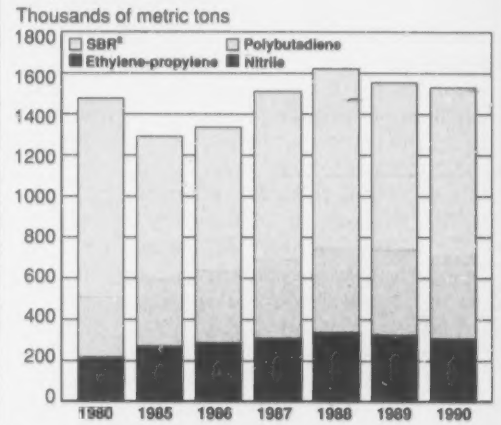
A major share of TPEs are various block copolymers of styrene. Butadiene, isoprene, butylene, and ethylene are examples of the comonomers. The special attraction of these elastomers lies in the ability to process them as plastics yet retain properties of vulcanized elastomers and in the ability to reprocess them as scrap.

Growth of TPEs has been high and will continue so, if forecasts prove accurate. New polymers and new entrants into the TPE field should keep growth steady. The use pattern also may be changed in the future, as new products come to market, but current major uses will grow substantially.

Between 40 and 50% of consumption is in adhesives and sealants. Much is used on packaging tape and on labels and as a bonding agent between different kinds of plastics. Modifiers for plastics and asphalts take another one third of consumption. TPEs add impact resistance to plastics. The modified asphalts are applied to fabrics and used as roofing materials in competition with EPDM and polyvinyl chloride. Many other products are made from TPEs, such as footwear, vicosity index improvers, parts for toys, housewares, automobile parts, wire and cable coverings, and medical device components. Growth should be well above the rate of other large-volume elastomers during the 1990s.

TPEs represent a faster changing part of the rubber or elastomers industry, notwithstanding that the whole industry is changing. Old-line elastomers are being modified to meet the new cost/performance demands from changing consumer products. By the year 2000, this industry will have changed more than during the 1980s, says IISRP's Tessmer. □

Little growth in U.S. rubber output in past decade



a Styrene-butadiene rubber; polymer and oil.
Source: Rubber Manufacturers Association